Chapter 10 Discussion and interpretation

10.1 Influence of the MCR layer on the distribution of alteration features

The investigation demonstrated that alteration mineral assemblages are predominantly developed in the area selected for the current investigation. These assemblages resulted from amphibolization, serpentinization, saussuritization, uralitization and talc-carbonate alteration of primary and secondary minerals. The occurrence of a talc-carbonate assemblage in the LHZBG Unit and especially the PCR Unit suggests the development of a deuteric CO_2-rich environment, and confirms the conclusions of van Zyl (1996).

It has been established by various authors that the lithological units below the MCR layer suffered the most severe alteration. In the Bushveld Complex the presence of the so-called mixed layer and UG2 pegmatoid below the UG2 chromitite has been suggested to have formed due to metasomatism and partial melting of the pyroxenite protolith (Mathez and Mey, 2005). In the model suggested by Mathez and Mey (2005) the UG2 pegmatoid formed due to a hydrous interstitial melt that percolated up through the partially molten crystal pile below the UG2. The hydrous melt accumulated beneath the pre-existing, compacted UG2 chromitite layer, which then led to the metasomatism and partial melting of the pyroxenite protolith. This material, upon cooling crystallizes, to form coarse-grained pegmatoid. The hydrous melt was however not able to cause partial melting of the UG2 chromitite, and this unit remained relatively impermeable. The model require the permeability of the chromitite to have been less than that of the underlying rocks, which may be possible if the chromite grain size are smaller than the grain sizes of the minerals constituting the underlying rocks. Another reason for the low permeability has been suggested to be due to the presence of interstitial plagioclase in the UG2 chromitite.

It is also suggested by Butcher and Merkle (1991) that the development of *in situ* cumulus plagioclase would have led to the complete elimination of porosity in the anorthosite that underlies the lower most magnetite layer found in the Upper Zone of the Bushveld Complex.

It has been reported by Theart (1997; 2000) that MCR layer has on average a thickness ranging from 0 up to six meters in areas without structural duplication. In this rock type, chromite represent as much as 85 mass % of the rock. The chromitite layers are internally laminated due to variation in abundance of chromite and interstitial silicate minerals. The interstitial silicates now consist of secondary chlorite, talc, and amphibole with minor serpentine, plagioclase, biotite and phlogopite (Theart, 1997; 2000). The chromite grain has an average size of about 100 micron (Theart, 1997; 2000).

It is suggested here that the MCR layer served as an effective barrier to the CO_2-rich hydrothermal fluids, confining these hydrothermal fluids to the basal units and concentrating the fluids in the PCR Unit. Thus, in effect, the MCR layer shielded the units above from the effects of the hydrothermal alteration and metasomatic processes that affecting the basal units.

In a similar vein Mathez and Mey (2005) noted that the Merensky Reef and UG2 chromitite layer are the only extensive layers that exhibit intense magmatic metasomatism in the entire Bushveld Complex. These two layers are also the economic sources of platinum group minerals. Mathez and Mey (2005) remarks that the possibility that metasomatism and metallogenesis were somehow related, but that the process remains enigmatic.

10.2 Association of sulphide mineralization with alteration mineral assemblages

Other ultramafic intrusions with associated nickeliferous sulphides, also host the economic sulphide deposits in rocks that have suffered alteration of the primary host rock. In the Platreef the economic mineralization has been found to occur in areas of the intrusion that has calc-silicate xenoliths present, that has been serpentinized, the highest concentrations of PGE, nickel and copper are found rimming the xenoliths (Gain and Mostert, 1982; Hammerbeck and Schurmann, 1998; Harris and Chaumba, 2001; Manyeruke, 2003; MacDonald et al., 2005; Kinnard et al., 2005). The economic sulphide mineralization at Selebe-Phikwe is associated with an amphibolite, although in this instance the regional metamorphic grade is also of the upper amphibolite facies (Snyman, 1996). The deposit in Shangani, Zimbabwe, is found in a serpentine-talc schist within a greenschist fragment (Snyman, 1996). The sulphide mineralization of the Pechenga deposits, in the Kola Peninsula, north-western Russia, is associated with serpentinized peridotite (Barnes et al., 2001).

The nickeliferous sulphides show a tendency to be associated with hydrothermal metamorphosed host rocks. This may be due, firstly, to extensive assimilation of country rock that release volatiles (CO_2, H_20, etc.) into the intruding magma. This will, secondly, result in an increase in the oxygen fugacity, with the effect being sulphur super saturation. Thirdly, a skarn and magma mix could have acted as a trap for sulphide droplets. Fourthly, under such magmatic conditions, the crystallization of typical magmatic sulphide mineral assemblages including: pyrrhotite, chalcopyrite, pentlandite and Platinum Group Minerals will occur. Lastly, retrograde metamorphic mineralization of magnetite and pyrite will modify and react with the magmatic mineralization. During this time there appears to be a bottom-up escape of hydrothermal fluid, and top-down introduction of immiscible sulphide fluids.

The relationship between metasomatism and metallogenesis may be explained by the following model: the assimilation of country rock, which contains hydrous minerals or has been hydrated due to prior metasomatism, by the intruding magma leads to an increase in the oxygen fugacity. Fluids may also be introduced into the system by a hydrous interstitial melt. The role of addition of H_2O and CO_2 to magma and the resultant precipitation of sulphides and spinels has been noted before (de Waal, 1977). This may result in the formation of e.g. sulphide or chromite deposist as was the case suggested for the Uitkomst Complex and Bushveld Complex. In the event of the formation of an impermeable layer higher up in the succession, the fluid will now become trapped beneath that layer. The overlying layer may be impermeable due to smaller grain size of the new mineralization regime, e.g. chromite grains of the UG2 layer in the Bushveld Complex or MCR layer of the Uitkomst Complex. It may also be due to the formation of adcumulus minerals or the presence of interstitial minerals that is either in equilibrium with the fluid or slow dissolution of the mineral in the fluid e.g.

primary plagioclase in the case of LHZBG Unit in the Uitkomst and the UG2 layer of the Bushveld Complex.

The fluid responsible for the precipitation sulphide or spinel from the magma would now be effectively trapped beneath this impermeable layer. This may lead to metasomatism (in the case of the Uitkomst Complex and Bushveld Complex) and if temperatures remain high enough, partial melting of the protolith (suggested in the Bushveld Complex). Upon cooling this fluid might lead to the formation of retrograde metamorphic alteration of the precursor minerals. This model would also suggest that the most intense alteration of precursor minerals will occur beneath the impermeable layer.

10.3 Discussion of the features in the lower parts of the Uitkomst Complex

In brief the possible sequence of alteration in the Uitkomst Complex may be summarised as:

1. The main mafic magma of the PCR and MHZBG Units on or near the contract Bevets conglomerates and the overlying shales and underlying Malmani Dolomite. The original extent of the conduit is represented by the lateral extent of the PCR Unit. Chromite grains segregated from the melt and formed the stringers and schlieren observed in the PCR Unit and the lower parts of the MHZBG.
2. The shale was more susceptible to magmatic erosion and developed into the broader dimensions observed in the current body. Due to the rapid broadening of the conduit upward less chromite grains could remain in suspension. This led to the development of the MCR Unit near the upper contact of the dolomite host rock. The broadening of the conduit also resulted in the decreased ability of the magma to suspend chromite grains. This resulted in preferential deposition of the MCR to form the three chromitite hills. The signature of the shale country rock is evident in the isotopic signature observed in the lower units.
3. The magma of the PCR did probably not suffer as much assimilation and hybridisation due to interaction with dolomite country rock, as xenoliths are

absent in this unit. This would also indicate a more rapid emplacement of this magma. Primary sulphides formed in the form of disseminated mineralization. Here the presence of both hexagonal and monoclinic pyrrhotite may support the hypothesis of less assimilation of country rock. Olivine preserved in this unit also indicates its magmatic source. Diopside composition points to a mixed source of magmatic and transitional material. This unit completely lacks skarn diopside.

4. The PCR Unit may have been emplaced by continual pulses of chromite-bearing magma source magma, as indicated by the chromite lenses layers and schlieren. The magma emplacing the PCR Unit would have started stoping into the Rooihoogte sediments, changing the range of elements contaminating the magma. The magma would now be contaminated by a Si and Al country rock component. The edges of the Complex in the PCR Unit may now be bound by a combination of skarn and hornfels at different stratigraphic heights.
5. The next phase of magmatic activity, that formed the LHZBG Unit, followed without a significant hiatus. The magma that formed the LHZBG Unit may have mixed with some of the residual peridotic/harzburgitic magma present in the conduit system.
6. The initial pulses of intruding magma intruded in a passive style. This led to a gradual downward development of the conduit and resulted in the formation of the skarn aureole in the lower third of the LHZBG Unit. The passive style of intrusion is demonstrated by the preservation of horizontal layering in the calc-silicate xenoliths. The siliceous dolomite rafts between the layers of intruded magma were thermally metamorphosed and formed diopside-rich calc-silicate xenoliths. Skarn rocks that formed prior to the intrusion of the lower LHZBG magma influenced the intrusion pattern of the LHZBG magma. The passive nature of the intrusion led to assimilation of dolomitic skarn xenoliths and the hybridisation of the magma. The collapse of xenoliths may have released a calcite-rich fluid into the hybrid magma. This is demonstrated by the presence of calcite that appears to be in equilibrium

with the surrounding magmatic minerals. The release of this fluid may also have contributed elements such as Ca, Fe and Mg that led to a decrease in viscosity of the hybrid magma. This decrease in viscosity may also have contributed to the preservation of xenoliths in the lower parts of the LHZBG Unit, as the less viscous hybrid magma may not have been able to suspend the xenolith blocks. This phenomenon may also be responsible for the formation of relatively large diopside crystals at the contact between the xenolith and the surrounding hybrid pyroxenite. The pegmatoidal rocks surrounding some of the xenoliths may therefore have developed at this time. The original magma responsible for the formation of the LHZBG Unit was more primitive in nature, and able to accommodate the addition of Ca. The addition of Ca led to the crystallization of Ca-rich minerals from the hybrid magma. The Ca-rich minerals that formed include: transitional range clinopyroxene (diopside) and Ca-amphiboles forming part of the solidification fronts that developed. The formation of these solidification fronts may have prevented the conduit in which the magma of the LHZBG was transported, from attaining the same lateral extent as the underlying BGAB Unit. Intrusion of magma during this stage formed the “foot” of the anvil-shape of the intrusion.

7. Magmatic fluids released during the intrusion would not be in chemical equilibrium with the siliceous dolomite rock and the elevated temperature would drive the decarbonation reactions. The decarbonation reactions may also have led to the release of CO_2 and H_2O and other volitiles that were taken up in fluids that migrated in or were removed form the conduit system. This may have resulted in the enrichments of elements such as: Mo, Nb, Ni, Y, Th, U, Y, Zn, S, and V towards the SE of the Complex, as determined by the isocon method. Evidence has been provided that the magma flow in the conduit was from the NW to the SE.
8. The magma may have become sulphur supersaturated due to the partial assimilation of dolomitic country rock and accompanying devolitization. The assimilation of dolomitic country rock led to an increase in oxygen fugacity,

lowering the FeO content and thus the sulphur carrying capacity of the magma. The magma may also have suffered contamination by Si, especially during the period the Rooihoogte sediments formed the roof. The system may also have been enriched with Si, as Al substituted for Si in the hybrid diopside, possibly leading to a slight increase in the Si content of the melt. The magma may also have been contaminated by sulphides derived from the dolomite country rock.

9. The initial pulses of magma forming the LHZBG Unit had a higher oxidation potential, which led to the formation of minor primary magnetite. The oxidation potential however lowered, which favoured the formation of nickeliferous sulphides. The preserved magnetite suffered silicification and where the grains came into contact with pyrrhotite, an exsolution rim of ilmenite and a Ti-rich phase formed.
10. The top-down infiltration of a sulphide fluid with a low viscosity resulted in the formation of the net-textured wehrlite layers. Here the sulphide fluid infiltrated between the magmatic derived olivine grains that had segregated from the melt. Hydrous acidic fluids associated with the sulphide fluids may have led to the partial or complete serpentinization of these olivine grains.
11. The initial contamination of the magma by volatiles may have led to the formation of high grade amphiboles like pargasite and hornblende, referred to here as the “first generation” amphiboles. These amphiboles, along with precursor mafic minerals such as olivine and clinopyroxene, and skarn minerals served as traps for the sulphide fluid. Evidence for this is found in the sharp contacts between the precursor minerals and hornblende grains and the interstitial sulphide grains.
12. The dynamic nature of the deuteric system may have led to the formation of the alteration assemblages observed throughout the LHZBG Unit. As the CO_2-rich fluids were removed from the system, the hydrous fluids would dominate the system. This would lead to the retrograde metamorphism observed in this unit. The hydrous fluids may have led to the further serpentinization of the preserved olivine grains, especially along cracks. This

resulted in the formation of serpentine and secondary magnetite assemblages. It would also lead to the formation of actinolite-tremolite pseudomorphs after diopside, referred to here as "second generation" amphiboles. These actinolite-tremolite grains are then intergrown with the interstitial sulphide grains, effectively reducing the size of the nickeliferous sulphide grains. The actinolite-tremolite grains are preferentially intergrown with the nickeliferous sulphides, in between the coarse grained pentlandite and the chalcopyrite rims around the main pyrrhotite grain. The migration of the fluids would also influence the distribution of the alteration minerals. These fluids may also have been responsible for the formation of late stage alteration derived magnetite and euhedral pyrite associated with the pyrrhotite grains.

13. The alteration assemblages observed in the LHZBG Unit vary greatly in distribution, both with spatial and height distribution. The most common silicate alteration assemblages observed in the LHZBG are: talc-dolomite (carbonate)-chlorite, talc-chlorite-tremolite, chlorite-serpentinte-carbonate, chlorite-serpentine-tremolite, hornblende-chlorite and hornblende-tremolite.
14. Amphibole has its highest abundance in the upper part of the LHZBG Unit close to the top of the unit, close to the margins of the trough and in the lower part of the unit in the broader part of the Complex. The amphibole content also seems to decrease from the north to the south in the study area. The talc content is highest in the upper part of the LHZBG Unit in the narrow part of the Complex and then again highest in the lower part of the unit in the broader area. The talc content decreases towards the southeast. The serpentine content increases towards the northwest. The chlorite content decreases from the north to the south in the study area. The hydrothermal metamorphism and metasomatism may already have commenced during the emplacement of the LHZBG Unit.
15. The MCR layer may have served as an effective barrier, preventing further upward circulation of fluids from the underlying units and concentrating the fluids in the PCR Unit.

16. The CO_2-rich deuteric fluid, being trapped under the MCR layer and bound by the skarn margins of the complex, affected the entire PCR Unit. The precursor minerals were metasomatically altered by the hot, acidic CO_2-rich fluid, to yield the observed completely altered matrix minerals observed in the PCR Unit. The extensive alteration of the PCR Unit may also have led to a substantial increase in the volume of the unit. The main alteration assemblages found in the PCR Unit are: talc-chlorite-amphibole, talc-carbonate-chlorite-amphibole, serpentine-amphibole, tremolite-hornblende and talc-phlogopite.
17. The amphibole content shows no vertical preference of occurrence but decrease towards the southeast. Talc has the highest occurrence in the upper part of the unit in the northwest of the study area and decrease in content towards the margins of the Complex. The talc content increases towards the southeast in the study area. Chlorite has its highest occurrence in the bottom part of the narrower part of the Complex and highest in the central part, decreasing in content towards the southeast of the study area. Serpentine is found to increase in content towards the southeast in the study area. This may indicate the hydrothermal fluids to have been more hydrous towards the margins and southeast of the Complex, in this unit, in the study area.
18. The deuteric fluid was able to mobilize certain elements to different extents. This led to the observed either enrichment or depletion of certain elements (Mg, Ca, K, Cu, Ga, Ni Sc, Cs and Ba) with depth, as determined by means of the isocon method. This may indicate a hydrothermal system operating vertically in the PCR.
19. Where the MCR layer was not developed, the CO_2-rich fluid was able to escape into the lower part of MHZBG Unit and affect it. This led to the formation of the LrPRD Sub-unit that was hydrothermally metamorphosed, though less so than the PCR Unit, but more than the rest of the MHZBG Unit. It may also have led to an increase in the oxygen fugacity that was enough to cause sulphide over saturation in the LrPRD Sub-unit and in some areas of the MHZBG Unit. Using the isocon method it was also established that

certain elements (Mg, Na, Zn, Co and Sc) were enriched or depleted with depth in the LrPRD. This indicates that the hydrothermal system operated vertically out of the PCR Unit into the LrPRD Sub-unit before entering the MHZBG Unit.

20. Preceding the “closed” phase of the conduit, the noritic magma was emplaced above the MHZBG unit and below the lower contact of the LHZBG Units. Work by previous workers indicated the composition of the BGAB and GN to not differ significantly.
21. The less mafic nature of the BGAB magma did not allow for the formation of Ca-rich minerals to form effective reaction fronts. The intrusion was such that little mixing and hybridisation with the dolomite host rock took place. Due to the lack of significant solidification fronts, a system of hydrous fluids may have developed and started to interact with the magmatic precursor minerals (hornblende, quartz and plagioclase) of the gabbroic rocks. This may have resulted in the observed secondary mineralogy in the BGAB Unit, consisting of actinolite, chlorite, muscovite and lizardite. The assimilation of country rocks and interaction with hydrous fluids, may have led to the general enrichment of elements (such as As, Ga, Mo, Nb, etc.) in the BGAB Units as determined by the isocon method.
22. Emplacement of the Marginal Gabbro may have been contemporary with the BGAB and GN Units. This unit was never as fully developed due to the limiting effects of the surrounding skarn.
23. The characteristics of the skarn aureole around the lower units (BGAB, LHZBG and PCR Units) may have prevented the infiltration of meteoric water during the initial stages of metamorphism. Thus, it may be assumed that the fluids responsible for the metasomatic alteration of these units were derived from the breakdown of dolomitic derived skarn and to a lesser extent magmatic fluids.
24. After most of the CO_2-rich fluids were removed from the system, the hydrothermal system may have become hydrous dominated. In the central part of the Complex, the preserved heat may have driven this hydrous system

that led to the late-stage chlorite alteration. This is demonstrated by the chlorite pockets on the amphibole grains. Since the chlorite alteration is most prominent in the central part of the Complex, it may indicate that the margins of the Complex may have had a moderating effect on the circulation system operating in the Complex at this time.

25. The BGAG, LHZBG and PCR Units were affected by tectonic events post-dating the cooling of the Uitkomst Complex that also had an effect on the alteration assemblages. Tectonic events that affected the Uitkomst Complex are discussed by Hornsey (1999). These include sub-vertical strike-slip faulting and thrusting. Thrusting is evident from the duplication of lithological units. Two main events are postulated; the first is related to the deformation of the contact between the PCR and the MHZBG Units, likely due to the increase of volume in this unit as the precursor minerals were altered. The second is related to regional deformation, with the most prominent feature being Basal Shear Zone. Related thrust zones within the Complex are represented by talc-chlorite schist zones. These shear zones may have provided pathways for minor fluids to infiltrate the Complex, leading to further alteration processes, possibly affecting mineralogy and leading to further volume changes.
26. The Uitkomst Complex may also have suffered minor alteration due to the intrusion of sills and dykes. The intrusion of the sills and dykes may have led to alteration of the host rock mineralogy in direct contact with the dyke and also affected the total volume of the Uitkomst Complex by dilation. The effect may be most profound in the PCR Unit where diabase intrusions exploited the weakened area of deformation between the MCR layer and the MHZBG Unit. It is conceivable that the intrusive event may have released some of the volatiles associated with the alteration minerals found in the shear zones.
27. Later processes responsible for the formation of the present escarpment exposed, weathered and eroded the Uitkomst Complex. Where the lower units (BGAB, LHZBG and PCR Units) are exposed on the farms Slaaihoek

and Vaalkop the units suffered weathering due to meteoric water infiltration. This changed the mineralogy, and resulted in the oxidation of silicate and sulphide minerals and the formation of hydroxide and clay minerals. The present overburden derived mainly from the Timeball Hill shale, Klapperkop quartzite and diabase, is variable in depth.

14.4 Conclusion

It is suggested that the presence and presevation of calc-silicate xenoliths in the Lower Harzburgite Unit, due to the formation of solidification fronts, may have been an important factor in limiting the hydrothermal alteration of the precursor mafic minerals in this unit. The second important factor may have been the up- and outward removal of the CO_2-rich fluids by the hydrothermal circulation system operating in a rapidly flowing conduit system emplaced at depth. The third factor, that may have limited the alteration in the LHZBG Unit, may be the physical properties of the skarn margin surrounding the intrusion, preventing the inflow of meteoric water.

It is suggested that the almost complete hydrothermal alteration of the precursor mafic minerals in the PCR Unit may be due the entrapment of CO_2-rich fluids in a deuteric system operating in this unit by the overlying MCR layer and ineffective removal of the CO_2-rich fluid through the skarn and reaction front surrounding the Uitkomst Complex. The hydrothermal fluid would be in effect “trapped” in the PCR Unit. The heat of the system will drive the CO_2-rich fluid upward and outward, but would be prevented from leaving the PCR Unit by the overlying MCR layer and the surrounding skarn solidification fronts. It is also considered unlikely that the fluid may cool and percolate back down into the, by now mostly solidified, LHZBG Unit. The fluid may then only have been able to be removed by escaping the system where the MCR layer is not well developed, into the LrPRD Sub-unit and MHZBG Unit, as long as the conduit system was still operational.

The proposed processes discussed in this section are illustrated by Figures 10.2 to 10.7. It should be noted that the processes discussed here is most likely to have been continuous, leading to successive alteration events and alteration assemblages. Later events, such as the intrusion of the dykes and tectonic remobilization may have led to a partial over print of the earlier recorded events.

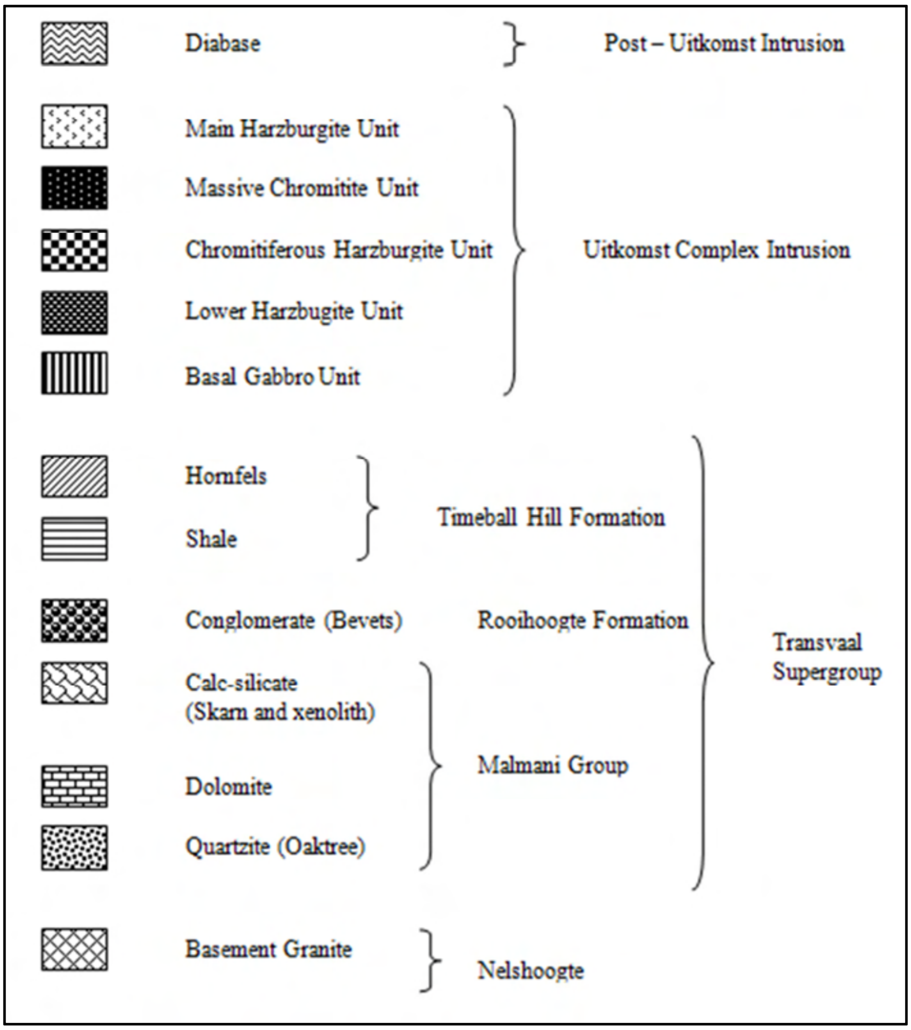

Figure 10.1. Legend to all diagrams in this section.

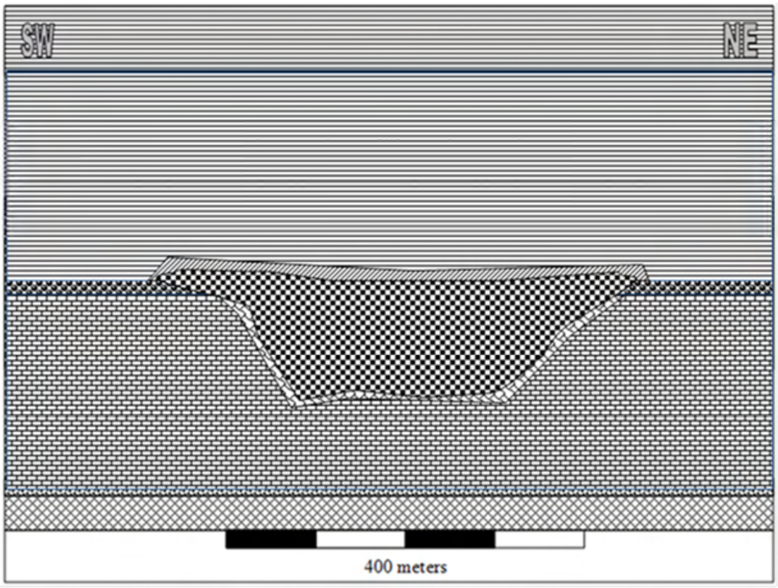

Figure 10.2. Initial intrusion of the PCR and MHZBG magma, between the Bevets Conglomerate and Oaktree Formations. This led to the formation of the first skarn and hornfels aureoles. Figure is looking down the conduit in a northwesternly direction.

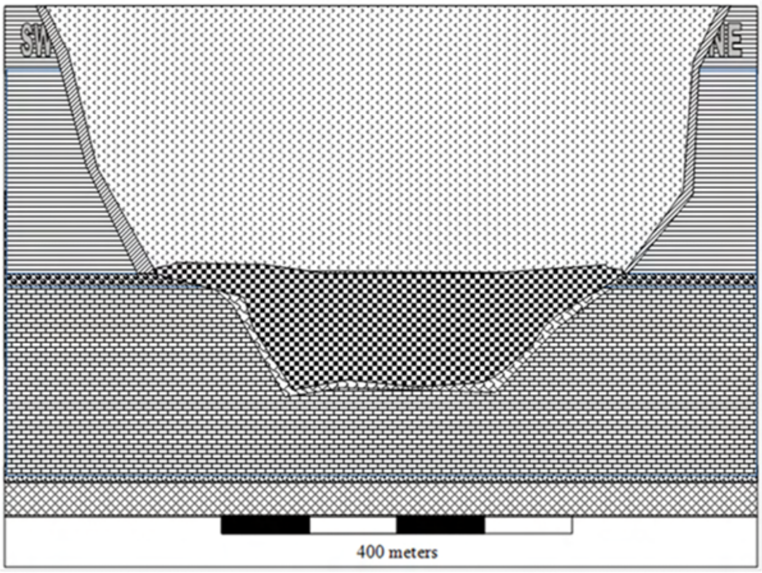

Figure 10.3. Intrusion of the initial pulses of the magma that formed the PCR and MHZBG Unit. Deposition of the chromitite layers and schlieren in the PCR. Rapid expansion of the MHZBG into the overlying shale roof rocks continue and minor hornfels development. Devolitization of the underlying Malmani Formation start and the fluid generated is expelled by the movement of magma in the conduit.

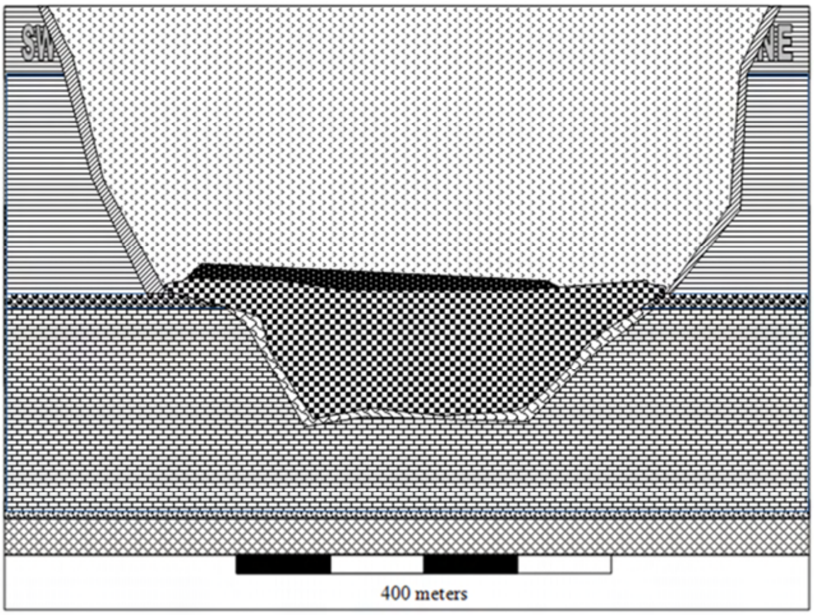

Figure 10.4. The upward expansion of the MHZBG Unit and localized broadening of the conduit resulted in the deposition of the MCR Unit. Further development of the thin hornfels aureole continue. Sulphide saturation is reached and droplets accumulate in a disseminated manner in the PCR Unit. Sulphide saturation is not attained in the MHZBG and only minor sulphide segregation takes place.

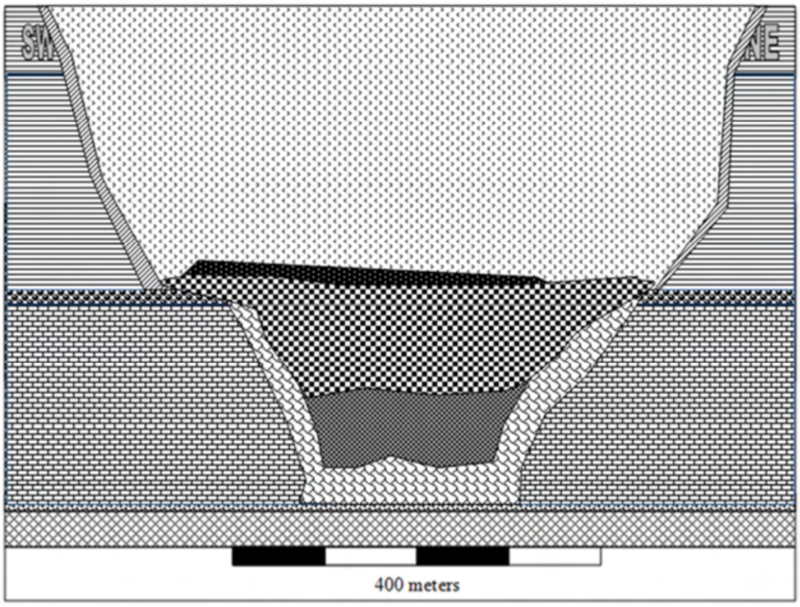

Figure 10.5. Intrusion of the LHZB G magma. Intrusion of the LHZBG magma scoured the bottom of the PCR Unit. The formation of extensive skarn along the margin and specifically in the lower third of the Unit take place. Sulphide saturation of the magma is reached. Devolitization of the country rock and included xenoliths take place. The fluid migrates upward and outward. The fluid migrates up to the PCR unit were it leaves the system less efficiently. Talc and secondary dolomite is stabilized.

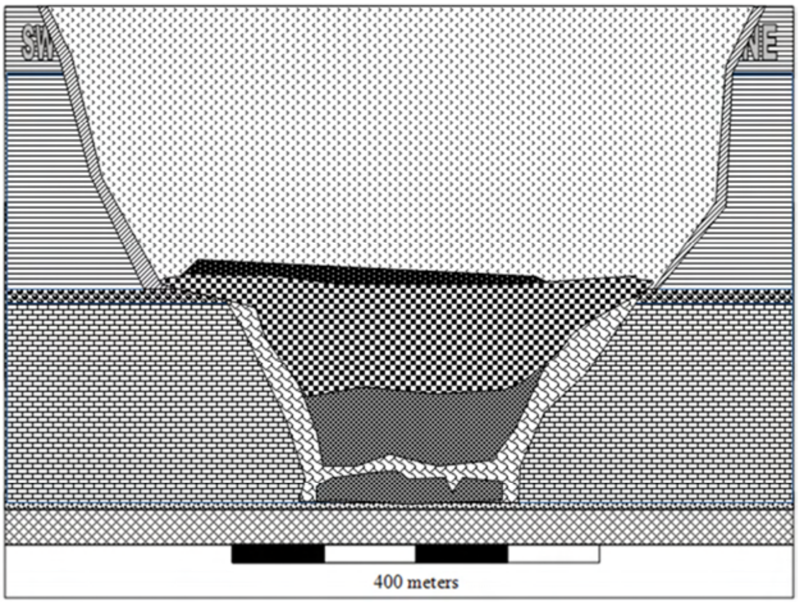

Figure 10.6. The passive emplacement of the LHZBG results in the preservation of the undisturbed calc-silicate xenoliths in the lower third of the intrusion. Devolitization of the country rock and included xenoliths continue. The resulting fluid migrates from the LHZBG, leaving the residual fluid more hydrous. This results in retrograde metasomatism of the overlying mafic minerals.

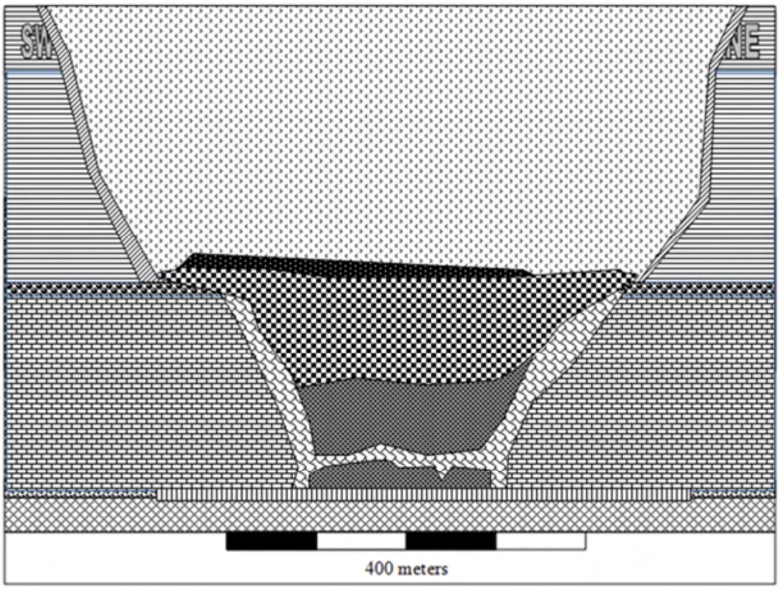

Figure 10.7. The BGAG Unit is emplaced. This unit is less mafic and interacts to a far lesser extent with the country rock. Devolitization of the country rock results in the alteration mineral assemblages observed in this unit. The fluid in the LHZBG is more hydrous, whereas the fluid in the PCR is more CO_2-rich

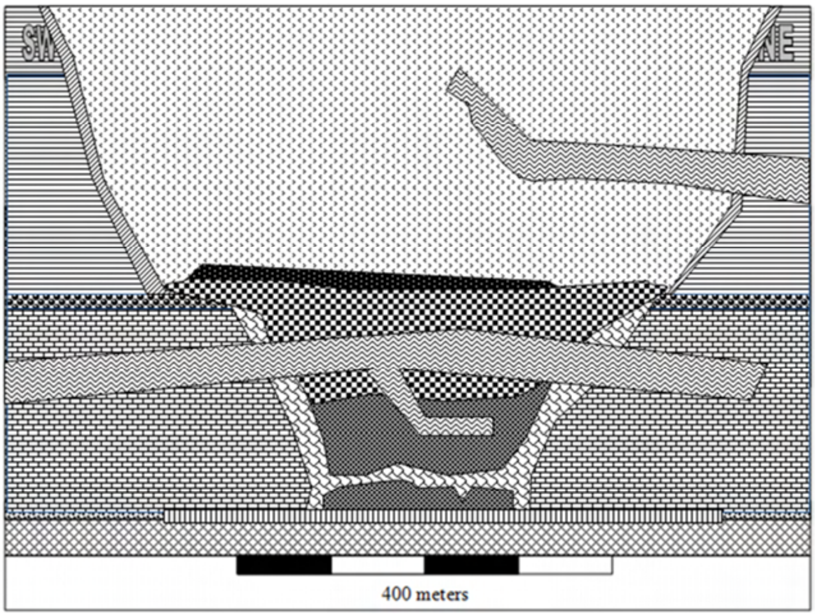

Figure 10.8. The Uitkomst Complex is intruded by diabase dykes and sills. The Complex suffers tectonic deformation. The Complex is weathered down to be exposed in its current form

An idealized section through the Uitkomst Complex is given in Figure 10.9. It is inferred that the main source of fluids was the assimilation of the dolomites. The meteoric water derived from the assimilated dolomite country rock would have migrated in the conduit. This would lead to the serpentinization of the xenoliths and the formation of the pyroxenite and amphibolite associated with the xenoliths. The lower part of the LHZBG will be affected by retrograde metamorphism. It has been determined that the migration of CO2-rich fluid would be up and outward, so the lower part of the unit will be dominated by a hydrous fluid. After the formation of the solidification fronts, no further fluids are expected to be expelled from the xenoliths into the magma. The fluids may now be driven upward, and not affect the precursor minerals in the lower part of the LHZBG Unit any further.

The CO_2-rich fluids would migrate up into the PCR Unit, and lead to the CO_2-rich deuteric system which results in the initial alteration of the PCR Unit. This may have resulted in the almost complete talc-carbonate alteration observed in this unit. Some fluid may, however, have been able to escape the system along the flow of the conduit. The fluid may also have been able to escape into the MHZBG Unit where the MCR layer is not developed, and led to the formation of the LrPRD Sub-unit. Some of the fluids, especially the CO_2-rich fluid may also have been able to leave the system along the margins, where the hornfels margins was not well developed. The resultant increase in volume of the PCR Unit due to the formation of the alteration assemblages is inferred to have led to the formation of the shear zone between the PCR Unit and MCR layer. Fluids may have migrated more effectively along the shear zone.

The system may eventually have become hydrous dominated. The occurrence of a late-stage cooler circulation system, only operating in the central part of the Complex, is proposed to have developed, with the margins having a moderating effect on the system. Meteoric water is not expected to have entered the Complex, influencing the hydrothermal system.

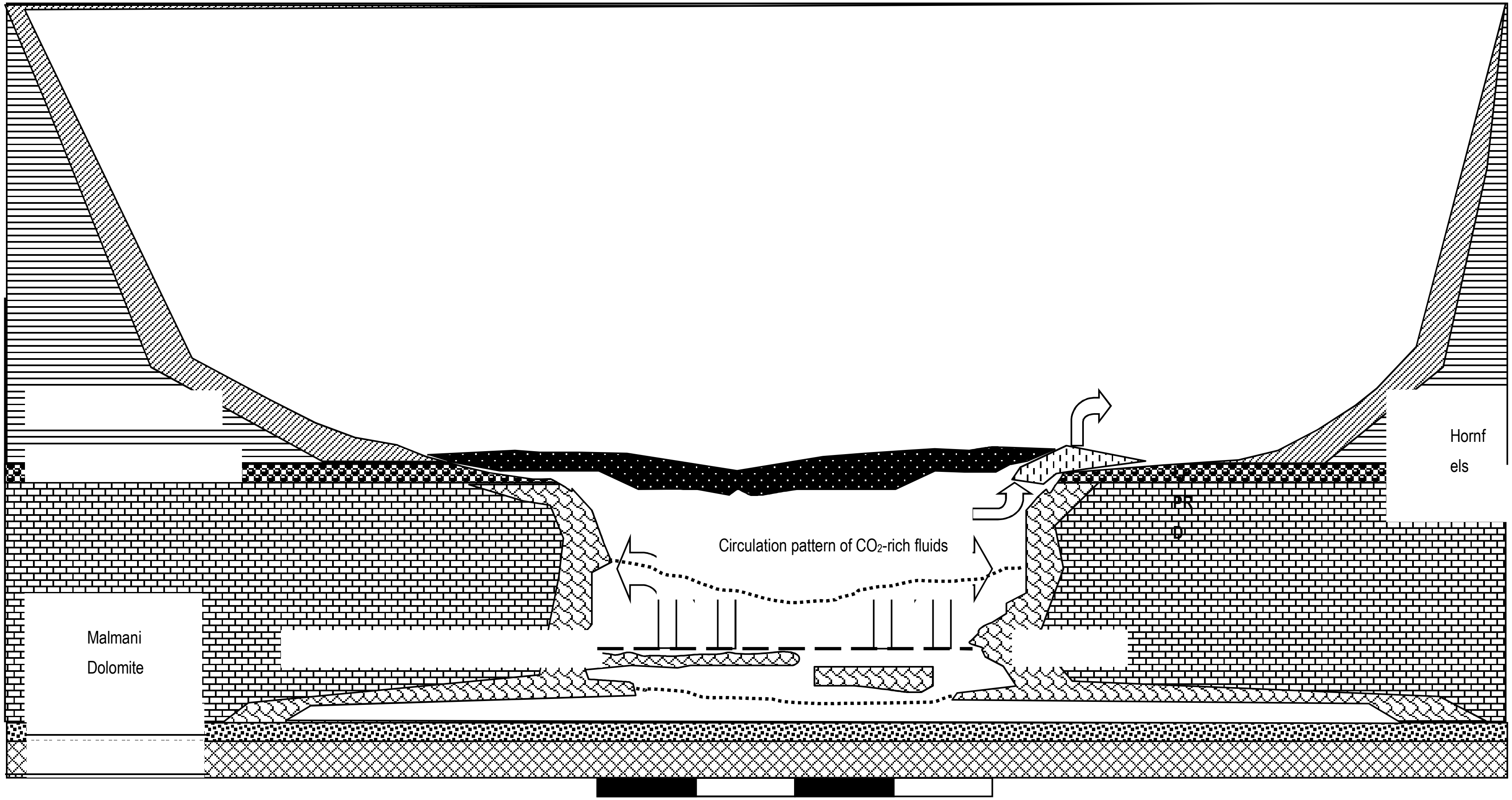

Figure 10.9. An idealized representation of the hydrothermal circulation system operating in the Uitkomst Complex.